Ocean Sci. Discuss., 11, C351–C362, 2014
www.ocean-sci-discuss.net/11/C351/2014/

Ocean Science
Discussions

Interactive comment on "Computation of a new Mean Dynamic Topography for the Mediterranean Sea from model outputs, altimeter measurements and oceanographic in-situ data" *by* M.-H. Rio et al.

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Received and published: 16 May 2014

The reviewer will find below the response to his questions/comments. All of them will be taken into account in the revised paper. Figures are included to support our response. They will be added/updated in the revised paper.

C90-1: .It should be reminded that the use of optimal interpolation or objective analysis for the mapping of mean fields does not rely on good theoretical grounds. Defining a covariance model (in a statistical sense, i.e. an average over many statistical realizations) for mean fields is questionable (see discussion in Davis, JGR, 1985). This is fine though to use it as any other interpolation method but this cannot be considered as an

"optimal" method. This cautionary note should be reminded.

Response:We agree with the reviewer and we will remove the "optimal" word from the revised text and add a cautionary note on the subject together with an adequate reference to Davis et al, 1985.

C90-2:Covariance models. Taking into account cautionary note above, it should be noted that the model used in this study was defined for mesoscale variability statistical characterization. It is likely that better models should be defined for mapping of mean fields.

Response: This is also a very important issue, and we will add some discussion about it in the methodology section as well as in section 5.1

C90-3: Handling of errors for hydrological data. Errors do not include systematic errors in the model mean dynamic topography. Do you really believe that CTD observations corrected from altimetry can give you local MDT as precise as 1 cm or less ? It seems to me that you are underestimating the errors on hydrological data. I understand this is difficult to estimate and that this would require taking into account correlated errors in the mapping procedure but this must be better discussed.

Response: See response given to point 8 below.

C90-4.I would have liked to have a discussion on the potential of GOCE. Given the fact that correlation scales of MDT (e.g. figure 14) and of existing/remaining errors are often much larger than 100 km I would expect/hope that GOCE will make substantial improvements for MDT estimation in the Mediterranean Sea

Response: When the study started, the first GOCE geoid models were already available but the accuracy at 100km was not sufficient enough to be used for our study. Today models are more accurate and the fifth release, still to come, should really make a big difference at short scales.

In the revised paper, the following section on the "potential impact of GOCE data" will be added: In Rio et al (2007), the use of a model first guess was dictated by the insufficient accuracy of the geoid models for computing a large scale MDT in the Mediterranean Sea from a filtered difference between a MSS and a geoid. At the present time, significant improvements have been made in our knowledge of the geoid at scales down to around 150 km thanks to the longevity of the GRACE mission and the launch in march 2009 of the GOCE satellite, whose objective was to measure the Earth geoid at 100km resolution with centimetric accuracy (Drinkwater et al, 2003). Still, the use of GOCE data to retrieve the Mean Dynamic Topography in the Mediterranean Sea is very challenging due to the geometry of the bassin (many coastal areas, narrow straits...) and the expected short scales of the ocean circulation (the Rossby Radius number is of the order of 10km). Left plot of Figure 21 shows the row differences between the CNES-CLS11 Mean Sea Surface (Schaeffer et al, 2012) and the EGM-DIR4 GOCE geoid model, that was computed from 7 years of GRACE data and 2 years of reprocessed GOCE data (Bruinsma et al, 2013). The right plot of Figure 21 shows the MDT obtained after filtering from the raw differences all scales shorter than 200km using a simple isotropic gaussian filter. We see that the main gyres of the Mediterranean Sea circulation don't close (the cyclonic circulation in the North Western Mediterranean basin, the gyres in the Adriatic Sea, the Alboran eddies, the anticyclonic circulation in the South Ionian basin). The main issue when using a GOCE model in the Mediterranean Sea for the MDT computation is that the large geoid omission errors (satellite-only solutions are calculated for scales greater than around 80 km, while the MSS resolves much shorter scales) coupled with a low oceanic signal variability result in a raw MSS-Geoid signal characterized by a very low signal to noise ratio. The short scale noise is too high to be correctly filtered. One way to go may be the use of so-called combined geoid models: In these models (e.g. EIGEN-6C2, Föerste et al, 2012), GOCE data are used to estimate the geoid scales larger than around 100km and the shorter scales are given by high resolution gravity anomalies derived from altimeter MSS information. The objective is not to use this short scale information for the MDT calculation but to reduce the amplitude of the signal to be filtered (the

scales shorter than 100km) to increase the filter efficiency. Also, more sophisticated filters should be used, as for instance the optimal filter described in Rio et al (2011). Finally, it is worth saying that a fifth release of the GOCE geoid models should be made shortly available by ESA to the community. This release will benefit from an extended measurement period relative to the fourth release and, most notably, from a lower orbit configuration of the satellite during the last year of the mission, which should bring significant improvements at scales down to 80-100km and therefore enable a more accurate estimate of the ocean Mean Dynamic Topography in challenging areas as the Mediterranean Sea. The use of GOCE data is one of the major perspectives of this work in the short term. We are confident that in the near future the use of an optimally filtered GOCE based MDT could be used as first guess to invert the high resolution synthetic mean heights and velocities and calculate a fully model independent MDT solution of the Mediterranean Sea.

C90-5- Page 5: isotropy. You are not using an isotropic covariance model.

Response: Right, we will correct this in the revised paper.

C90-6- Page 5: removing a large scale field (first guess) does not mean that the mean field is zero. Do you take this into account (as proposed by Bretherton et al., 1976)?

Response: No we don't take this into account indeed, and this is something we should improve in the future. We will add a note on this point in the revised paper.

C90-7- Page 8 : a map showing the values of alpha (and their seasonal variations) would be quite useful to discuss. Any error bars on the alpha estimations ?

Response: We will update Figure 6 in the revised paper.

On this updated plot, the α parameter monthly evolution is shown. The dashed lines on Figure 6 represent the uncertainty enveloppe of the α350 parameter, calculated using the standard deviation of the regression error.

C90-8- Page 8: adding an estimation of the missing component to mean dynamic height at 350 m will add errors and biases in the hydrological MDT observations. This must be discussed (see point 3 above).

Response: This missing component is estimated as the difference between the MFS modelled MDT (Figure 2a) and the mean synthetic dynamic heights relative to 350m computed from observations. The MFS model is used here to be consistent with the first guess used for the MDT calculation (see section 5.2). This approach is equivalent to considering that only the short spatial scales of the synthetic dynamic heights relative to 350m (hdyn/350-α350SLA) will be used in the inversion to correct the modelled first guess, i.e. it assumes that the modelled first guess is perfect (no associated error). The final error on the synthetic heights are calculated as the box variance divided by the number of observations in the box. The obtained error is lower than 2-3 cm in most places. It does not take into account the error on the modelled first guess, and is therefore surely underestimated if taken as an estimate of the full depth absolute dynamic topography. However, considering the approach used here, these data are intended to contribute to correct/improve only the first 350m of the water column first guess. These considerations will be added in the revised paper.

C90-9- Page 9: you estimate the reduction of drifter velocity variance due to the altimetry derived correction. I assume you did a similar calculation for hydrological profiles (page 8) but this is not discussed. Why ?

Response: In the revised paper, the following section will be added, including reference to 2 additional figures (figure 7 and figure 8 below): The efficiency of using α350m times the altimeter SLA to remove the temporal variability of the dynamic heights is caracterized on Figure 7: The top plot shows the standard deviation of the dynamic heights calculated into 0.25° by 0.25° boxes. The middle and bottom plots show the the standard deviation, expressed in percentage of the standard deviation of the dynamic heights, of the dynamic heights from which the temporal variability has been removed, either using the altimeter SLA (middle plot) or using only a part of it (α350SLA). Values greater than 100% thus correspond to boxes where subtracting the temporal variability

from the signal leads to increased variability, i.e. some noise has been introduced. Using the full SLA to remove the variability increases the variability in most places, while removing only part of it through the use of the α350 coefficient leads to a reduction of the box standard deviation in most places, which makes us confident on the appropriateness of this approach. However, in some remaining boxes (percentage greater than 100%, in white on the bottom plot of Figure 7), noise is introduced by this method. We check (Figure 8) that this corresponds to boxes with only few data and, again, that the approach is satisfying in most of the boxes. In these boxes, no correction of the variability is applied on the dynamic heights (α350m=0).

C90-10- Page 9: you should explain the 30% (resp. 40%) fig ures.

Response: These values have been taken from a paper by Le Traon et al, 1999 and Pascual et al, 2007. The reference to these papers will be added in the revised text.

Le Traon, P.-Y., Dibarboure, G., 1999. Mesoscale mapping capabilities from multiple altimeter missions. Journal of Atmospheric and Oceanic Technology 16, 1208–1223.
Pascual, A., Pujol, M.-I., Larnicol, G., Le Traon, P.-Y., Rio, M.-H., 2007. Mesoscale Mapping Capabilities of Multisatellite Altimeter Missions: First Results with Real Data in the Mediterranean Sea. Journal of Marine Systems 65, 190–211.

C90-11-Page 10: why not using both Eq. 3 and Eq. 4 to adjust x0 and y0 ? Why not using a first guess MDT model and estimate from it x0 and y0 ? see also point 1 above.

Response:We actually did use the first guess MDT model to compute the correlation scales, but did not show the result in the original paper. We will update table 2 with this sensitivity results (see table 2 below) and add some text to comment it in the revised paper.

C90-12- Page 10: why not giving also the Eq. for < U V > ?

Response:We did not put the equation for <U,V> because we do not use it in this study.

C90-13- Page 11: Tables 1, 2 and 3 should also give the rms of drifter velocities.

Response: Values will be added in the Table’s legends.

C90-14- Page 13: why not using your alpha estimations to compare CTD profiles to the MDT ?

Response: Alpha estimations have been calculated from temporal anomalies of dynamic heights relative to 350m and altimeter Sea Level Anomalies. They may not be valid to translate the CTD dynamic heights relative to 350m to absolute dynamic topography values. Indeed, we have recalculated the comparison statistics applying the coefficients on the absolute heights and the obtained results are not better, so we plan to keep the same comparison procedure (i.e. not applying the alpha parameter) in the revised paper.

Interactive comment on Ocean Sci. Discuss., 11, 655, 2014.

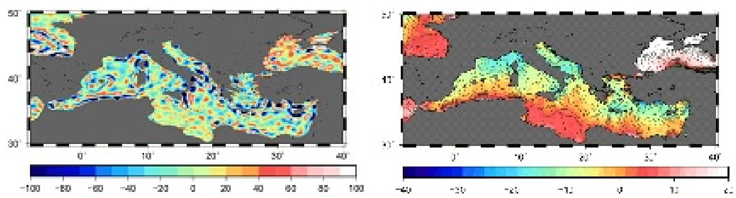

Figure 21: Left: Raw difference between the CNES-CLS12 MSS and the EGM-DIR4 GOCE geoid. Right: A 200km low-pass filter was applied on the raw differences.

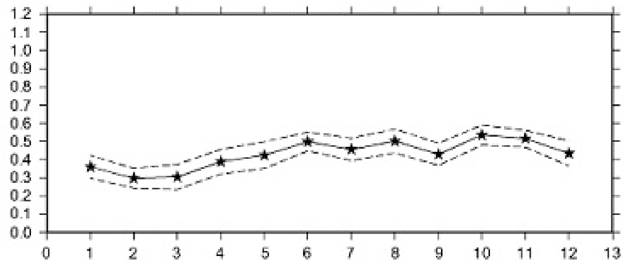

Figure 6: α parameter obtained using a 3 months moving window .The dashed lines give the uncertainty envelope of the obtained parameters.

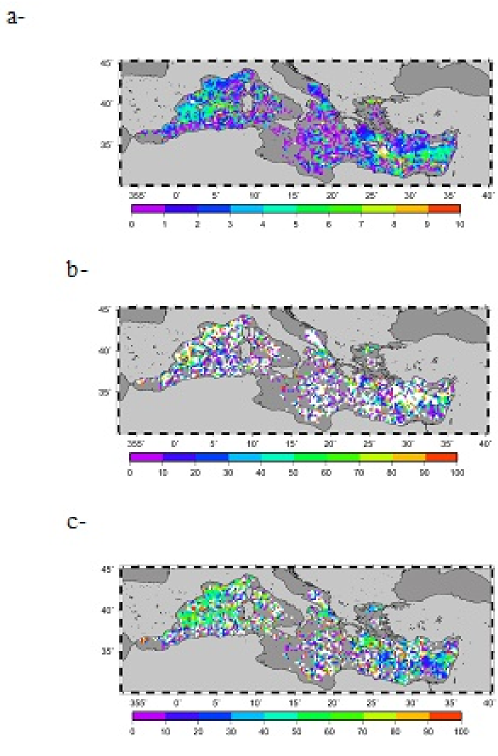

Figure 7: a- Standard Deviation of the dynamic heights (cm) b- Standard Deviation of the dynamic heights corrected from the altimeter SLA, expressed in percentage of the dynamic heights standard deviation c- Standard Deviation of the dynamic heights corrected from the altimeter SLA times the α coefficient, expressed in percentage of the dynamic heights standard deviation.

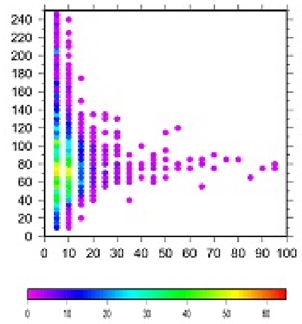

Figure 8: Signal standard deviation reduction obtained as a function number of observations used to compute σ_{350m} (5 observations interval are considered). The color scale gives the number of boxes

Table 2. Rms differences (in cms/s) between the processed independent drifter velocities and the altimeter velocities calculated using 4 different MDT solutions, based on the use of correlation scales deduced from the analysis of the zonal or the meridional drifter velocities of the MFS MDT, or the NEMO MDT. The RMS of the zonal (resp. meridian) drifter velocities is 15.5 (resp. 15.2) cm/s.

	SMDT RcDrifter U,U	*SMDT RcDrifter V,V*	*SMDT RcMFS*	*SMDT RcNEMO*
RMS($U_{Drifter}$ - U_{Exp})	16.7	17.0	17.8	17.1
RMS($V_{Drifter}$ - V_{Exp})	15.3	15.4	15.6	15.3